Sustainable technology and product innovation in the built environment: Biomimicry potentials

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Abstract
Sustainable technologies and products balance the triad of economic, social and environmental aspects of sustainability in their creation. The unavailability of which has retarded the growth of the built environment via-a-vis sustainability. For over 3.8 billion years, nature has been in development with time-tested patterns and strategies. This has given birth to biomimicry, an applied science that offers solutions to human challenges through the study and emulation of nature's forms, processes, and systems. With the global quest for sustainability, the role of nature has become more convoluted, becoming a supreme role model of efficiency, effectiveness, and collaboration. This has however portrayed the potential of biomimicry as an effective concept and practical tool in the innovation of novel products and technologies with sustainable attributes. This paper reviews the current knowledge on the potential of biomimicry in the development of products and technologies for the built environment. The findings indicate that stakeholders in the built environment have little or no knowledge of materials birthed from biomimicry. A definite knowledge of biomimicry approach is also lacking thereby preventing its successful application. The study, therefore, explores biomimicry and its potential in heralding an era of novel innovations for the sustainability of the built environment.

Keywords
Biomimicry, innovation, nature, sustainability, built environment, sustainable technologies and products.

1. Introduction

Buildings and infrastructures which are the products of the construction industry, continuously generate a large amount of pollution and waste thereby having a long-term impact on the environment and the inhabitants (Wang, 2014). This impact is what makes the industry a major sector involved in achieving sustainability (Shi et al., 2012). The goal of sustainability is defined as the improvement of the efficiency, health and performance of the built environment (Kibert, 2002; Du Plessis, 2007; Kibert, 2016). In a bid towards achieving sustainability of the built environment, much pressure has been put on the construction industry, for stakeholders to improve on its current unsustainable practices (Adetunji et al., 2003; Opoku & Fortune, 2011). This has propelled a global quest towards moving the built environment to the sustainability path. As articulated by the Conseil International du Batiment (CIB), the principles of sustainable construction are: reduction in resource consumption; reuse of resources; use of recyclable resources; protection of nature; elimination of toxics; application of life-cycle costing and focus on quality (Kibert, 2016). These seven principles are also widely summarised as reduce, reuse, recycle, nature, toxics, economics and quality.

Researchers have however identified different barriers to the successful implementation of sustainability of the built environment. One major barrier widely identified is the lack of environmentally sustainable materials and products amongst others (Shafii et al., 2006; Szydlik, 2014; Ametepey et al., 2015). Most of the technologies and products available in the construction market are known to be negatively impacting the natural and human environment. Waste generation (resulting in pollution of all kinds), greenhouse gasses emission (resulting in the depletion of the ozone layer and its subsequent global warming and climate change), consumption of natural resources and large amount of energy are few of the attributes associated with these technologies and products (Shafii et al., 2006; Azis et al., 2012; Pearce et al., 2012; Akadiri & Fadiya, 2013; Wang, 2014). As a mitigation step, the Architecture 2030 Challenge for Product addresses the emissions associated with building materials and products, setting a goal of maximum carbon-equivalent footprint reduction to 35% and 50% below the product category by the year 2015 and 2030 respectively (Kibert, 2016). It is, therefore, imperative to encourage the innovation, production and saturation of the built environment with technologies and materials possessing minimal or zero environmental footprints. This has the potential to paddle the global sustainability movement in the right direction, a step believed by many researchers will aid the sustainability of the built environment.

Historically, there are contentious, iconic and interesting records of nature-inspired innovations and technologies believed to posses sustainable attributes. These includes innovations in the medical and pharmaceutical sciences; shelter and shelter architectures; weapons and defence, including armours, sensors, and alarm systems; agriculture and food production; and processes related to manufacturing (Murr, 2015). Owing to its over 3.8 billion years of evolution, nature has become an extraordinary role model for a harmonious balance and proportion (Radwan & Osama, 2016), encompassing efficiency, collaboration, resource utilisation, and longevity. Hence, biomimicry, a novel field that describes the emulation of nature's time-tested patterns and strategies to postulate sustainable solutions to human challenges. This paper discusses the essence of sustainable materials towards the successful implementation of sustainability in the built environment. It also discusses the overview of biomimicry, approaches that aid its application and its innovative prowess as evident in biomimetic products and applications. The aim of this study is to unveil the potential of biomimicry in the innovation of sustainable technologies and products for the built environment.

2. Overview of Biomimicry

Coming from a combination of the Greek words *bios* (life) and *mī́mēsis* (imitation), biomimicry literally means life imitation or the imitation of life (De Pauw et al., 2010; Arnarson, 2011; Murr, 2015). Nature has become a rich source of knowledge, and present-day human life has undoubtedly progressed because of our ability to be inspired by nature, and to then innovate solutions to our problems through biomimicry (Nychka & Chen, 2012). Quoting Janine M. Benyus, a biologist, author and co-founder of the Biomimicry Institute, biomimicry is "the process of learning from and then emulating life's genius. It's based not on what we can extract from the natural world, but what we can learn from it. Life has been on earth for 3.8 billion years, and in that time life has learned what works and what fits here. Mimicking their designs, strategies, and their recipes could change the way we grow food, power ourselves, conduct busi-ness, even the way we make our materials" (Benyus, 2011). Biomimicry is now on the forefront of scientific and technological research, because it brings about novel insights for the synthesis of biologically-compatible, environmentally-friendly and energetically-efficient materials (Zhang et al., 2015).

2.1 Biomimicry principles

Biomimicry principles, some of which are obvious and self-explanatory, are abstracted biological strategies that can be found in most of the organisms, which enables life to be successful in regenerating itself (Jacome Polit, 2014). In the book titled 'Biomimicry: Innovation Inspired by Nature', through which biomimicry was popularised, Benyus (1997) resonates under-listed nine nature principles which are also the basic principles underpinning the concept of biomimicry. They are (i) nature runs on sunlight; (ii) nature uses only the energy it needs; (iii) nature fits form to function; (iv) nature recycles everything; (v) nature rewards cooperation; (vi) nature banks on diversity; (vii) nature demands local expertise (viii) nature curbs excesses from within; and (ix) nature taps the power of limits. It is upon the above-listed life's principles that the Biomimicry Institute presented a more comprehensive one as shown in Fig 1.

Figure 1: Biomimicry/Life's Principles (Biomimicry Group, 2014)

2.2 Biomimicry approaches

Biomimicry approaches help redefine the levels of biomimicry and clarify its potential as a tool for sustainability. These approaches offer unique focal points, explicit methodologies and step-by-step paths under the larger umbrella of biomimicry (Niewiarowski & Paige, 2011), providing an avenue for the application of biomimicry in innovative sustainable technologies and products for the built environment.
The Biomimicry Institute (2014) propagated eight (8) definite steps for easy application of biomimicry. They include define; identify; integrate; discover; abstract; brainstorm; emulate; and measure. These steps are further categorized into scoping, discovering, creating and evaluating (Biomimicry Institute, 2014). On the other hand, Zari (2007) and Helms et al., (2009), proffered six (6) steps as follows: Problem definition; reframe the problem; biological solution search; define the biological solution; principle extraction; and principle application. The above-mentioned steps and categories constitute the two approaches of biomimicry, though with different terms as postulated by researchers and authors. They are problem-based approach and solution-based approach.

2.2.1 Problem-based approach

The Problem-based approach is also known as Design Looking to Biology Approach (Zari, 2007), Problem-Driven Biologically Inspired Approach (Helms et al., 2009), Top Down Approach (Knippers, 2009; El-Zeiny, 2012), Problem-to-Solution Approach (Pandremenos et al., 2012; Buck, 2015) and Challenge to Biology Approach (Biomimicry Group, 2014). This approach entails defining a human need/challenge by understanding and conceptualising the processes and structures that organisms or ecosystems optimise to resolve similar issues (Gamage & Hyde, 2012). Here, the natural world of organisms is looked unto for solutions which require identifying the problems and then matching the problems to organisms in nature that have solved similar issues. This approach is effectively led by designers, innovators, and engineers identifying initial goals and parameters for the design (El Ahmar, 2011).

The pattern of this approach follows a progression of different steps which, in practice, is nonlinear and dynamic in the sense that output from later stages frequently influences previous stages, providing iterative feedback and refinement loops (Helms et al., 2009). This approach is also believed to be a step towards transiting the built environment from an unsustainable state to an effective and resilient paradigm (McDonough & Braungart, 2010; El-Zeiny, 2012), as it helps in the innovation of sustainable technologies and products. In other to successfully achieve the innovation of technologies and products with zero environmental footprints, it is important to follow clock wisely (represented by the arrow in the diagram below), the constituting steps in this approach as shown in Fig 2.

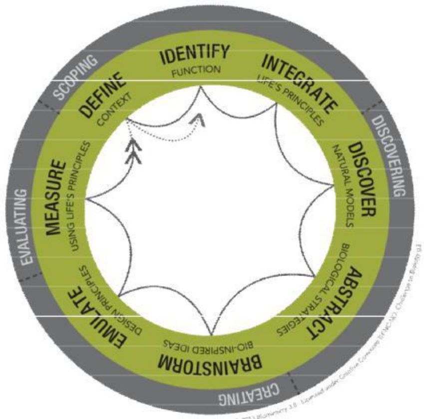

Figure 2: Problem-based Approach (Biomimicry Group, 2013)

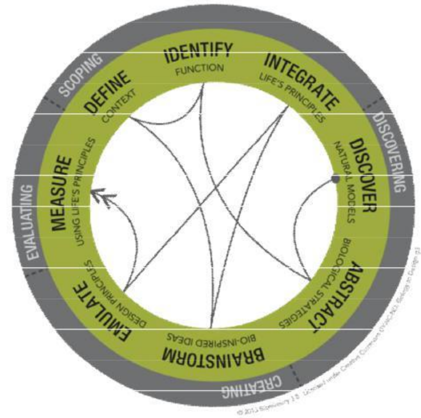

Figure 3: Solution-based Approach (Biomimicry Group, 2013)

2.2.1 Solution-based approach

Solution-based approach can also be referred to as Biology Influencing Design Approach (Zari, 2007), Solution-Driven Biologically Inspired Approach (Helms et al., 2009), Bottom Top Approach (Knippers, 2009; El-Zeiny, 2012), Solution-to-Problem (Pandremenos et al., 2012; Buck, 2015) and Biology to Design (Biomimicry Group, 2014). This approach involves identifying a particular attribute, behaviour or function in an organism or ecosystem thereby translating such into human designs, solutions or innovations (Zari, 2007). This approach entails a situation whereby biological knowledge influences the innovation of human design, technology, and product. The resultant innovation addresses one or many of the numerous materials deficit in the built environment. The collaborative design process is dependent on stakeholders having knowledge of relevant biological or ecological research rather than on determined human design problems (El-Zeiny, 2012). This approach follows an indefinite path/steps as represented by the arrow in Fig 3.

3. Biomimetic Technologies and Products

Sustainable products and technologies are those materials that do not impact the environment in a negative way. Their attributes encompass the principles of sustainable construction in its entirety, in others words having sustainable credentials. As posited by Sirinterlikci (2010), these products aim to reduce resource utilisation and its consequences from the human environment while maximising the added value and quality observed during all stages of the product's life-cycle. Since the goal of biomimicry is to increase the sustainability of the built environment (Vincent et al., 2006), biomimetic technologies and products should possess sustainable attributes in other not to contradict this goal. To date, there is a growing number of technologies and products informed by biomimicry. A critic of these products reveals their nontoxic, multifunctional, recyclable, and energy-efficient attributes amongst many others. Below are few biomimetic products and technologies carefully selected based on their relevance to the built environment.

3.1. Entropy carpet

The carpet company, Interface, has worked together with the Biomimicry Institute to manufacture sustainable closed-loop products. Inspired by the organized chaos of a blanket of fallen leaves and a bed of river stones, David Oakey and his team working for Interface FLOR discovered that none of nature's examples had exactly the same color makeup and contents, yet collectively they each created a complex and cohesive pattern (El-Zeiny, 2012). El-Zeiny (2012) further reported that it is chaos because no two stones, no two leaves, no two sticks look alike, yet there is a pleasant orderliness in the chaos, said Interface Inc. Chairman, Ray Anderson. With the discovery, "Interface" now design totally random tiles, each slightly different in pattern and color. This increases the flexibility, makes installation faster, repair easier, and reduces waste. Further, Interface designed a carpet tile installation system that uses small adhesive squares to connect carpet. By this, the company omitted the need for glue and made the installation process easier and faster, resulting in 90% lower environmental footprint (Ásgeirsdóttir, 2013). Interface, due to the success of Entropy carpets, has introduced a new line of sustainable biomimicry-inspired carpets called I2 and hundreds of other related products. This carpet offers a sustainable option for material selection by architects and interior designers for specification of floor finish for different kind of buildings.

3.2. Eco-Cement

TecEco eco-cement is a carbon neutral cement with inspiration drawn from the ability of various organisms (i.e. algae and plants), to synthesize structural materials like cellulose. The porous microscopic architecture of the setting cement allows CO_2 to permeate through the material, reacting with the magnesium hydroxide to form magnesium carbonate, a mineral that confers extra strength and rigidity. (AskNature, 2016). CO_2 is effectively trapped as a solid mineral within the concrete through its process of forming magnesium carbonate. The biomimetic TecEco eco-cement offers a ubiquitous construction material that traps atmospheric CO_2 which is a sustainable alternative to the traditional Portland cement known to significantly contribute to the amount of CO_2 in the atmosphere (Oguntona & Aigbavboa, 2016b).

3.3. Lotusan paint

This paint is inspired by lotus plants (*Nelumbo nucifera*) live in typically muddy aqueous habitats, yet stay dirt-free without using detergents (see Fig 4). This is accomplished through the micro-topography of their leaf surfaces, making the plant extremely water-repellant (superhydrophobic). Dirt particles on the leaf's surface stick to water droplets on the leaf and when the water droplets roll off, the attached dirt particles are removed with them, thus cleaning the leaf without using detergent (Barthlott & Neinhuis, 1997). This phenomenon is popularly known as the 'self-cleaning effect'. The self-cleaning property is highly important for water plants. This natural phenomenon occurring in lotus leaf led to the finding of a new self-cleaning paint. Surface finishes inspired by the self-cleaning mechanism of lotus plants and other organisms, including many large-winged insects; have been applied in *i.e.* self-cleaning paint (Lotusan®) and clay roof (Erlus Lotus® clay roof), reducing the need for chemical detergents and costly labour (Ásgeirsdóttir, 2013) for maintenance and cleaning purposes. The paint surface takes the shape of densely packed ridges or bumps, just like the bumps found on lotus leaves, preventing water drops from spreading out, instead, the drops roll off the surface taking the dirt with them (El-Zeiny, 2012). Zari (2007) informed that the application of this paint will enable buildings or the surfaces they are applied to be self-cleaning.


Figure 4: Lotus plants and lotus-inspired lotusan paint (Zari, 2007)

3.4. Other examples

The proposed desalination plant called *Teatro del Agua* in the Canary Islands by Grimshaw Architects is another example. Teatro del Agua is a biomimetic technology (inspired by the Namib desert beetle's survival in the extreme desert condition where there is minimal rainfall but short infrequent morning fogs) projected to be self-sufficient in water with a large surplus that can supply neighbouring buildings (Zari, 2010). Embracing such biomimetic technology will be able to address the issue of drought and water challenges which are few impacts of climate change now felt globally (Oguntona & Aigbavboa, 2016a).

The floating Ecopolis (also known as lilipad) is a self-sufficient floating city that addresses housing displaced people due to ocean swell and flood (Rao, 2014). The Ecopolis is inspired by the highly ribbed leave of the great lilypad of Amazonia Victoria regia, an aquatic plant from the family of Nympheas with exceptional plasticity (Vincent Callebaut Architect, 2016). The Ecopolis is entirely recyclable, produces its own oxygen and electricity by recycling the CO_2 and the waste, thereby taking up the four main challenges launched by a climatological study of the Organization for Economic Cooperation and Development (OECD) which include; climate, biodiversity, water, and health. This biomimetic technology has the potential to help achieve smart and green cities as it does not deplete or pollute the environment. It is also noteworthy that there are several other biomimetic products and technologies either commercialized, patented or at the development stage, all proven and tested to be sustainable.

4. Conclusion

Growing the number of products and technologies with environmentally-friendly attributes as options to the available unsustainable is important for the sustainability of the built environment. Nature offers a world and database of novel innovative ideas that if well tapped into, has the potential of repositioning the built environment. Since nature has been able to evolve with near perfect strategies through its over 3.8billion years of research and development, a change of paradigm is imperative on the part of the stakeholders. Tapping into nature's rich knowledge base promises the innovation of recyclable, biodegradable, multifunctional, nontoxic, and high performing technologies and products. The steps involved in the biomimicry approaches should, however, serve as a guide in every case of its applications while the resultant innovations must be checked against the principles of biomimicry in other to ensure they are holistically sustainable. Since a clear biomimicry approach is lacking thereby hampering its successful application, stakeholders in the built environment should get acquainted with the nitty-gritty of biomimicry. Also, patronage and use of the available biomimetic products and technologies should be encouraged among the built environment stakeholders. Collaboration and sound relationship between biologists and stakeholders in the built environment should also be encouraged as it promises to birth an era of numerous sustainable biomimetic materials and technologies.

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